Quarterly Report
July - September 1997

Michael D. King and Si-Chee Tsay
Goddard Space Flight Center
Greenbelt, MD 20771

Abstract

Our major achievements of this quarter were: (i) the successful delivery of the MOD_PR06OD *V2* algorithm, and (ii) the overall analysis of SCAR-B and other observational data for various publications.

I.   Task Objectives

With the use of related airborne instrumentation, such as the MODIS Airborne Simulator (MAS) and Cloud Absorption Radiometer (CAR), our primary objective is to extend and expand algorithms for retrieving the optical thickness and effective radius of clouds from radiation measurements to be obtained from the Moderate Resolution Imaging Spectroradiometer (MODIS). The secondary objective is to obtain an enhanced knowledge of surface angular and spectral properties that can be inferred from airborne directional radiance measurements.

II. Work Accomplished

a.   MODIS-related Instrumental Research

To prepare the CAR for FIRE-III Arctic campaign in May 1998, we plan to do a thorough calibration and characterization of the CAR. We hope to determine if the CAR has a polarization sensitivity, test to see if any visible light is contaminating the UV channel, and to determine stray light errors. In addition, if the new supporting equipment (monochromator, new brighter lamp source, etc.) are functional by the time the CAR is calibrated, we hope to determine total spectral throughput of the CAR for all channels up to 1.7 μm. It is hoped this work can be done in April 1998, after the University of Washington has finished integrating the CAR into their new CV-580 research aircraft. While work was underway to vicarious calibrate the CAR-UV channel, we discovered that there was a manufacturing flaw in the UV filter—a spurious transmission at ~365 nm. This flaw caused at least 2/3 of the signal to be from outside the designed spectral bandwidth specifications. Thus, UV-B data gathered during the MAST, ARMCAS, SCAR-B, and TARFOX experiments are contaminated by UV-A radiation. It is recommended that two narrowband filters (FWHM no more than 5 nm) at least 40 nm apart replace the old UV-B channel for aerosol studies with the new CV-580 aircraft. We prefer the 340 and 380 nm bands, based on the fact that reflectances at both channels are already well known from nearly 20 years of TOMS and SBUV measurements.

b. MODIS-related Data Processing and Algorithm Study

The cloud retrieval algorithm, MOD06OD version 2 package, was delivered to SDST in early September using the MODIS electronic code delivery system. The package includes MOD06OD version 2 source code and the supporting system items required by version 2 delivery. The communications with SSTG (Science Software Transfer Group) personnel confirmed that our delivered package was accepted by CMO (Configuration Manage Officer) and passed to SSTG for further review. While the structure of the code is complete, several subroutines and data files (notably, MOD28 and MOD43 processing package for ancillary data, atmosphere correction, and QA) will be modified in a later update. Interfaces, including ECS metadata procedures, most-updated L1B, L1A (geolocation) and cloud mask readers were integrated into the package and a new HDF output procedure was re-written for MOD06OD, due to the new requirements of HDF-EOS and combining MOD06 products. The first release of the ancillary data creating package was also integrated into the version 2 code and fully tested. The ancillary data processing package includes clouds heights (from MOD06), land temperature (from DAO and from NCEP of surface air temperature), ocean temperature (from DAO and NCEP), mean temperature above cloud (from MOD07, NCEP, DAO, and standard atmosphere), precipitable water above cloud (from MOD07, NCEP, DAO, and standard atmosphere), and surface albedo (from CERES/SARB map). Interfaces to read in the intermediate ancillary data were completed and integrated. Due to processing differences between the cloud retrieval (process one instrument scan each time) and the ancillary data procedure (process one whole granule each time), the code structure had to be modified and was completed.

In the atmospheric correction routine, the current delivery simply returns constant values of above-cloud atmospheric transmittance while the final version will use a lookup table of precalculated transmittance values. Further sensitivity studies on the transmittance of the seven channels (applied by MOD06OD) will be conducted by using the correlated-k-distribution method. Lookup tables of one-way and two-way transmittance at different solar zenith angle, viewing angle, water vapor load, and cloud-top-pressure will be created for each of the seven channels by combining the correlated-k-distribution calculations using several standard atmospheres. However, with the completed code structure in place, SDST has agreed to begin integration of the code. Development of the atmospheric correction subroutine and the QA subroutine is ongoing. The thermodynamic phase algorithm is also under developing by performing forward calculations of reflectances and asymptotic parameters of ice and water clouds. The ratios of reflectances at several wavelengths will be determined as functions of solar zenith angle, viewing polar angle, relative azimuthal angle, cloud optical depth, and effective particle diameter for both water and ice clouds.

We have completed and delivered the code to perform space-time aggregation of MODIS atmosphere products; i.e. code to produce Level-3 daily gridded files

from a collection of Level-2 granules. This code will be used to aggregate all products (aerosol over land, aerosol over ocean, water vapor, clouds, and ozone) for the Atmosphere group. A significant design change was made to add several (in some cases, as many as 25) local attributes to each Scientific Data Set (SDS) in the Level-3 file specification, and use the values in the Level-3 file to control the processing of each parameter. Although this has caused a significant delay, we believe the code will be substantially more robust and flexible. The local attributes serve several functions. First, they control which statistics are produced, by indicating that the output SDS is derived from the input values through simple spatial averaging. Other local attributes may hold the ancillary information needed to compute certain statistics (e.g., the bin boundaries to be used when histograms are computed). In addition, the attributes help to document the processing path taken at run time. Most parameters, for example, make use of a Quality Assurance value theat is stored as a bit string in a byte array in the Level-2 granule. These QA values are used to exclude some observations from the daily averages. The specification of which bits from which byte array are now determined by local attributes in the Level-3 file, so that users of the daily averages will know exactly how that have been computed. Finally, the output files are now guaranteed to be consistent with the file specification. Changes to the desired output, therefore, can be performed simply by changing the file specification. Various MOD products with prescribed means and standard deviations were created as synthetic data suite to check the flow of Level-3 processing package and find any bugs.

Multispectral images of the reflection function and brightness temperature in 10 distinct bands of the MAS, acquired in SCAR-B, were used to derive a confidence in clear sky (or alternatively the probability of cloud), shadow, fire, and heavy aerosol. In addition to multispectral imagery, monostatic lidar data were obtained along the nadir ground track of the aircraft and used to assess the accuracy of the cloud mask results. Our comparisons between remote sensing-derived values of the heavy aerosol and fire mask and high resolution imagery and monostatic lidar measurements demonstrate that the aerosol mask properly detects heavy aerosol over land during daytime in Brazil, at least during the biomass burning season. As presently implemented, the heavy aerosol mask is not applied when the reflection function at 2.19 µm ($R_{2.19}$) exceeds 0.2. Hence, for deforested areas and urban/suburban environments, conditions for which $R_{2.19}$ is typically larger than 0.2, the heavy aerosol mask is not tested or applied. In the optically thinner regions of the MAS scene, heavy aerosol is more likely to be detected off nadir than at nadir, due largely to the fact that the heavy aerosol thresholds are not view-angle dependent, as they should be. At least for the spatial resolution of MAS (50 m at nadir), it is extremely easy to detect hot fires due to their strong thermal contrast to their surroundings. In our application of the fire mask, we used the 3.74 and 11.02 µm bands of MAS, though we could very well have utilized the 2.19 or 3.90 µm bands.

The cloud mask also appears to work well in Brazil, except under extremely thick

aerosol conditions for which the reflection function at 0.87 μm ($R_{0.87}$) exceeds our expectations for aerosol scattering. Under these optically thick conditions, the thickest part of the aerosol layer is misidentified as cloud ('fumulus'). The isolated cumulus mediocris clouds and the fire-induced cumulus congenitus clouds appear to be properly identified as cloud. Furthermore, our results for the shadow mask appear to work best for cloud shadows on the ground, and not very well for shadows of upper clouds on lower clouds. Areas where the shadow mask has its greatest difficulties are burn scars, which are naturally quite dark, especially in the forward scattering direction. This analysis shows that the cloud and aerosol mask being developed for operational use on MODIS, and tested using MAS data in Brazil, is quite capable of separating cloud, aerosol, shadow and fires during daytime conditions over land. All MAS flights for SCAR-B have been processed to level-1b (calibrated and geolocated radiances) using final radiometric and spectral calibration, with data sent to the Langley Research Center DAAC (Distributed Active Archive Center). In addition, browse images, a MAS data user's guide, software for unpacking and interpreting the data, and information on where and how to obtain data, are accessible via World Wide Web (http://ltpwww.gsfc.nasa.gov/MAS).

Three types of surface spectral anisotropy (i.e., cerrado, dense forest, and heavy smoke over dense forest) measured by CAR during SCAR-B campaign were analyzed and submitted for publication. Based on the analysis of these measurements, results show distinct spectral characteristics for various types of surfaces. The spectral anisotropy of cerrado, dense forest, and heavy smoke over dense forest revealed fairly symmetric patterns around the principal plane, with varying strengths and angular widths of the hot spot (backscattering peak in the anti-solar direction). In the shortwave-infrared region, the aerosol effect is suppressed and these hot spots are clearly seen in the bidirectional reflectance of the smoke layer over dense forest. In the 0.869 - 1.271 μm range, the shape of the hot spot is spiky; while the strength is reduced and becomes broader towards longer (e.g., 1.643 and 2.207 μm) and shorter (e.g., 0.472 and 0.675 μm) wavelengths, where chlorophyll absorption prevails. A secondary peak in the backscattering direction exists near 75° for the 0.869-1.271 μm range over cerrado and dense forest (but not for the smoke layer), and diminished for the 0.675, 1.643, and 2.207 μm channels. This phenomenon may be related to multiple scattering among leaves with particular leaf angle distributions.

These detailed measurements of the angular distribution of spectral reflectance have been used to compute surface albedo. Large discrepancies are found between these spectral albedos and those of the measured nadir reflectance. These angular and spectral dependencies can be utilized to retrieve either surface characteristics, using a few independent parameters, or aerosol microphysical and optical properties (e.g., size distribution and single-scattering parameters), if proper physical and radiation models are used. The CAR measurements, combined with the boundary layer aircraft measurements of aerosol physical properties and radiosonde observations, form an unprecedented data set with many

scientific results anticipated following more extensive radiative transfer modeling in the future.

c.   MODIS-related Services

1.   Meetings

1. **Michael King and Peter Soulen attended the** *Third International Airborne Remote Sensing Conference and Exhibition,* **held in Copenhagen, Denmark, on July 7-10, 1997, and presented papers "MODIS Airborne Simulator: Radiative properties of smoke and clouds during ARMCAS and SCAR-B" and "Cloud Absorption Radiometer: Airborne measurements of clouds and surface reflectance," respectively.**

2. **Si-Chee Tsay attended the** *IAMAS Symposium on Radiative Forcing and Climate,* **held in Melbourne, Australia, on July 1-9, 1997, chaired a session on** *"Radiative Forcing by Aerosol,"* **and presented a paper on "Sensitivity analysis of cloud forcing in the Arctic."**

3. **Si-Chee Tsay attended the IGARSS'97 Remote Sensing—A Scientific Vision for Sustainable Development, held in Singapore, on August 3-8, 1997, and presented a paper on "Global monitoring and retrievals of atmospheric aerosols and clouds."**

4. **Michael King and Si-Chee Tsay attended the CERES Science Team meeting, held in Corvallis, OR, on September 16-18, 1997, and presented a paper on "Cloud mask and cloud properties retrieval in the Arctic: ARMCAS results."**

5. **Steve Platnick and Michael King regularly attended weekly MODIS Technical Team meetings. Steven Platnick participated in MCST reflectance solar calibration issues, especially those effecting the SWIR bands. This includes analyzing the impact of the recently discovered 2.5 and 5.3 µm light leakage problem.**

2.   Seminars

1. **Tsay, S. C., "Global Monitoring and Retrievals of Atmospheric Aerosols and Clouds," at the Center for Space Remote Sensing Research, National Central University, Taiwan, August 11, 1997.**

III. Anticipated Activities During the Next Quarter

a. **Continue to test and refine our delivered MODIS** *v2* **cloud retrieval algorithm, including the cloud mask interface, ice/water cloud libraries/logic tree, thermodynamic phase, and QA flags;**

b. **Continue to analyze MAS, AVIRIS, and CLS data gathered during the ARMCAS campaign, as well as AVHRR, University of Washington C-131A in**

situ data, and surface data, all with the express purpose of helping to develop the MODIS cloud masking algorithm;

c. Continue to analyze MAS, AVIRIS, and CLS data gathered during the SCAR-B and TARFOX campaigns, as well as University of Washington C-131A in situ and radiation data to study aerosol mask and aerosol-cloud interactions;

d. Continue to analyze surface bidirectional reflectance measurements obtained by the CAR during the Kuwait Oil Fire, LEADEX, ASTEX, SCAR-A ARMCAS, SCAR-B, and TARFOX experiments;

e. Attend the Landsat (October 21-23) and MODIS (October 22-24) science team meetings to be held at Goddard Space Flight Center and Holiday Inn, MD, respectively.

f. Attend the Earth Observation and Environmental Information conference (October 13-16) in Alexandria, Egypt.

IV. Problems/Corrective Actions

No problems that we are aware of at this time.

V. Publications

1. King, M. D., S. C. Tsay, S. A. Ackerman and N. F. Larsen, 1997: Discriminating heavy aerosol, clouds, and fires during SCAR-B: Application of airborne multispectral MAS Data. *J. Geophys. Res.*, submitted.

2. Tsay, S. C., M. D. King, J. Y. Li and G. T. Arnold, 1997: Airborne spectral measurements of surface anisotropy during SCAR-B. *J. Geophys. Res.*, submitted.

3. Ji, Q., S. C. Tsay, Y. J. Kaufman, G. Shaw, W. Cantrell, 1997: Ground-based measurements of aerosol characteristics in biomass burning smoke and in urban/industrial pollution. *J. Geophys. Res.*, submitted.

4. Kaufman, Y. J., P. V. Hobbs, V. W. J. H. Kirchhoff, P. Artaxo, L. A. Remer, B. N. Holben, M. D. King, S.-C. Tsay, E. M. Prins, D. E. Ward, K. M. Longo, L. F. Mattos, C. A. Nobre, J. D. Spinhirne, A. M. Thompson, J. F. Gleason, and S. A. Christopher, 1997: The Smoke, Cloud and Radiation Experiment in Brazil (SCAR-B). *J. Geophys. Res.*, submitted.

5. Kaufman, Y. J., R. Kleidman, M. D. King, and D. E. Ward, 1997: SCAR-B fires in the Tropics: Properties and their remote sensing from EOS-MODIS. *J. Geophys. Res.*, submitted.

6. Gao, B. C., W. Han, S. C. Tsay and N. F. Larsen, 1997: Cloud detection over arctic region using airborne imaging spectrometer data. *J. Appl. Meteor.*, submitted.

7. Ackerman, S. A., C. C. Moeller, K. I. Strabala, H. E. Gerber, L. E. Gumley, W. P. Menzel and S. C. Tsay, 1997: An infrared retrieval algorithm for determining the effective microphysical properties of clouds. *Geophys. Res. Lett.*, **submitted**.